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**AUDITORY VIGILANCE AS AFFECTED BY SIGNAL RATE  
AND INTERSIGNAL INTERVAL VARIABILITY**

by

Richard L. Martz

Bureau of Medicine and Surgery, Navy Department  
Research Work-Unit MR005.14-2001-5.01

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## SUMMARY PAGE

### THE PROBLEM

To investigate a group of variables having to do with the problem of auditory vigilance in the submarine situation. The variables chosen were signal rate and intersignal interval

### FINDINGS

If the signals came fast and frequently, (2.5 to 120 per hour at 0 to 1-1/2 minute intervals) there was no decrement of auditory vigilance, however, when slowed to rates of 2.5 to 7.5 per hour and fifteen or more per hour, there was a latency of response (in one group of subjects) It was found that time-on-watch had some overall effect in the direction of slowing down responses

### APPLICATIONS

The information presented in this report will be of use in those military situations where target detection and signal recognition are important

## ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Project MR005.14-2001-5, "Psychophysiological Studies of Auditory Factors in Submarine Operation." It has been designated as Report No. 1 on the indicated Work Unit and was approved for publication on 2 July 1965

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# AUDITORY VIGILANCE AS AFFECTED BY SIGNAL RATE AND INTERSIGNAL INTERVAL VARIABILITY

## INTRODUCTION

The frequency at which signals occur, and their distribution in time, provide perhaps the most obvious set of independent variables affecting receiver behavior in the detection situation. The slope of the relation comparing per cent detections and signal rate has been described by several investigators. Deese and Ormond (1953), whose subjects detected dim pips appearing on the face of an oscilloscope at rates between 10 and 40 signals/hr, showed that probability of detection and signal rate correlated positively with a slope of approximately 1.25. Other investigators have reported flatter slopes of less than 1.00, Jerison (1959) reporting on signal rates between 10 and 60 signals/hr in a complex task involving multiple visual signal locations Jenkins (1958) on signal rates ranging between 7.5 and 480 signals/hr in a simple Mackworth-type clock hand study, and Nicely and Miller (1957) on signal rates of 12 and 72 signals/hr in the appearance of PPI radar pips at two quadrant locations.

If the percentage measure in these studies represents a tabular change in more primary sensory or central sites, it should be possible to express this relation directly in terms of a threshold change as a function of signal rate or variability. Zwisllocki et al (1958), found that tone thresholds are sensitive to short-duration runs within sessions continuing no longer than one hour. While the thresholds of Zwisllocki's naive subjects improved from day to day, sensitivity within each session became worse. In a vigilance situation where subjects might trace their thresholds repeatedly in time without interruption, threshold may be sensitively correlated with signal rate and intersignal interval distributions.

Several investigators employing an ascending method of limits have obtained threshold data in vigilance situations. Wertheimer (1955) tested graduate and undergraduate students in a series of auditory and visual threshold sessions. He found that threshold values varied markedly as a function of time-on-watch, but that no trends were otherwise apparent. Elliott (1957), investigated tone pips in noise. Contrary to Zwisllocki et al, he found that thresholds improved from day to day. Bakan (1955) working with a constantly-observable patch of light, found that the difference threshold to slight increments in the brightness of this light increased with time-on-watch.

Gettys (1964) has also found this decremental effect with auditory noise signals, but did not find this decrement to be differentially affected by signal rates of 40 or 80 signals/hr.

Although signal rate, and the variability of intersignal intervals around this rate, become increasingly interdependent as signal rate increases, these variables have not been studied together. Studies on the variability of intersignal intervals have not presented a clear picture of its effect, if any, upon detection. Mackworth's (1950) subjects showed a definite decrement in signals detected as a function of time on watch when the intervals between signals varied between 45 sec and 10 min. Baker (1958, 1959), in a replication of Mackworth's study, confirmed his general finding, and showed that when the range of intersignal intervals was reduced from 45-600 sec to 36-196 sec, no in-watch decrement occurred. Jenkins (1958) found that the probability of detection, following a detection, dropped in time from an originally high level. Deese and Ormond (1953), however, in one experiment measuring response latencies as a function of intersignal interval, found latency and interval duration to be uncorrelated.

The present study was designed to investigate these variables of signal rate and intersignal interval variability concurrently under identical procedural operations, using subjects from two populations in an extended auditory threshold task.

## METHOD

Subjects: Twelve Navy enlisted personnel and twelve civilians were employed, six Ss from each group participating in each of two experiments. The enlisted personnel, ranged between 18 and 21 years of age, and were assigned to experimental duty while waiting military travel orders. Paid volunteer housewives between 20 and 45 years of age, and a 69-year-old retired Navy officer, also served.

Apparatus: S sat alone in a well-lighted, sound-dampened room and listened to continuous white noise at 70 dB sound pressure level (re .0002  $\mu$ bar) delivered binaurally over Telephonics Company TDH-39 earphones. Presented in this noise from time to time were pulse trains of 25-sec pure tones at 1 kc. Successive tones in each train were presented every 5 sec, beginning at 6 dB below S's pre-established threshold and increasing in 2-dB steps (ascending method of limits) until S pressed a microswitch, signifying detection. Thus, for each and every train of ascending intensity stimuli there

was a response. All tones were generated by a Hewlett Packard oscillator, Model 200 ABR, times and shaped by a Grason-Stadler Co. Electronic Timer, Model 471, and Switch Model, 829, and recorded along with S's microswitch responses as pips on a Brush strip-chart recorder.

Procedure: S was tested daily, one hour a day, for six days. Each session began with a 6-min threshold test consisting of 12 trains of 1 kc tones. The mean dB level of S's response to these 12 items determined his "relative threshold zero" for that day's 48-min vigilance session which followed immediately. In Experiment I, in which rate of signal presentation was the variable under study, S traced his threshold daily on one of 6 different signal rates: 2, 6, 12, 24, 48, and 96/48 min. According to a latin square design (Edwards, 1950, p.319-327), each of these experimental conditions systematically preceded and followed every other condition once. The intervals between signal trains on each condition were drawn randomly from a rectangular distribution of intersignal intervals whose values ranged through  $\pm 1$ , 2 and 3 sigma around the mean interval of each signal rate. Sigma values in sec were chosen such that the ratio of sigma to the mean interval of each signal rate was held constant (as a coefficient of variation) at 1/15. Thus, for example, for the signal rate of 96 signals/48 min, in which a signal occurs on the average every 30 sec, sigma was  $1/15 \times 30$  sec, or 2 sec. Multiplying this sigma value by equal numbers of  $\pm 1$ , 2 and 3 sigma deviations around the mean interval, then, produced the rectangular distribution of intersignal intervals employed at this signal rate: 24, 26, 28, 32, 34, and 36 seconds. Each random sequence of intervals drawn for each rate condition was used with all Ss.

In Experiment II, in which the experimental design was identical to that of Experiment I, S was tested each day on the same signal rate - 48 signals/48 min - but on one of 6 different intersignal sigmas: 0, 1, 2, 6, 7 and 8 sec. Once again, each condition preceded and followed every other condition once, and intersignal intervals varying by  $\pm 1$ , 2 and 3 sigma were randomly chosen and fixed at each sigma condition for all 12 Ss.

The intersignal intervals employed in each experiment, along with the numerical relations producing them, are shown in Table I.

S was instructed only to listen for signals and to press the microswitch each time he thought a signal occurred. No criterion for signal occurrence was introduced, and in only two cases, one military and one civilian, were Ss who responded nearly continuously during pretest audiograms instructed to adopt a more strict criterion.



Data in each experiment consisted of six 48-min records for each of 12 Ss. The dependent variables analyzed were (1) dB with respect to "relative threshold zero," (2) response latency, and (3) false-positive responses.

## RESULTS AND DISCUSSION

### Subject Differences

Preliminary F-ratio tests for homogeneity of variance for threshold and response-latency data supported the hypothesis that military and civilian groups were drawn from the same auditory population. A difference appeared on threshold as a function of signal density.

### Signal Density

Figure 1 shows the mean thresholds in dB as a function of signal density, the rate at which signals were presented, taking both groups together, had no pronounced regular effect upon threshold. Some of the military deteriorated about 3 dB at the 2 signals/session condition. These thresholds show a general loss of 1-4 dB across all signal densities with respect to each session's pre-test threshold "zero." This loss is a bit larger than that typical for test-retest accuracy under short-term audiometry, where headphones are not removed and replaced between threshold crossings (see Harris and Myers, 1954 Table 10, showing a standard deviation of less than 1 dB for 5 Ss at 1 kc).

### Signal Variance

Similar results obtained for the interstimulus interval sigma means, shown in Figure 2, from the data at 48 signals/48 min session. The curves describe no effect of changes in interval on threshold.

Results of separate analyses of variance for rate and variance (see Tables II and III) show no strong trend for threshold to change as a function of signal rate, variance, order, or sessions. Signal rate in Experiment I, and sessions in Experiment II, reach formal significance at the 5 per cent level of confidence.

### LATENCY.

Figure 3 shows the means of response latency as a function of signal density. The negatively decelerating slope of the civilian curve indicates that latency of response clearly differentiates responses to infrequent signals from responses to frequent signals. This relation was substantiated by the

results of an analysis of variance of latency. Orthogonal comparisons (Walker and Lev, 1953, p 356) among the civilian latency means showed that the latencies of detections at these rates was two-valued, and that the signal rate of 12 signals/48 min was critical, above that rate, reaction time did not change, and below that rate, response time was categorically longer. Orthogonal comparisons of Navy rate mean response times, however, failed to show a similar effect of signal rate, on latency and a comparison of Navy and civilian reaction times showed that only at the 2- and 6-signal points did these times differ. It is well known that reaction time is correlated with age and is lower for males than females.

Latency as a function of intersignal interval distribution for Navy and civilian groups is shown in Figure 4. Aside from an erratic reading at 4 sigma in the civilian group, no effect on latency of detection response as a function of sigma is evident. Analysis of variance results of this data is shown in Table III

#### TIME ON WATCH

How individual data contributed to the overall means of these experiments is shown in Figure 5. The four pairs of curves in this figure are representative threshold and latency records of four Ss taken in 3-min segments throughout the 96-signal session. The upper curve of each pair is the threshold curve, the lower curve is the latency. "X" at the left of each threshold curve locates "relative threshold zero." The upper two threshold curves show slight elevations (2-3 db) in threshold within the first few minutes which are maintained well into the session. In the uppermost curve this elevation is permanent, in the lower curve some recovery occurs by end of session. This immediate elevation within a few minutes of the session beginning is not present in the third threshold curve, which shows no consistent decrement in sensitivity, and at some points some gain over the pretest threshold level. The bottom threshold curve, typical enough of most curves during the first half of the vigilance session, shows during the latter half of the session that this subject is apparently falling asleep. At one point in the final 15 min, this subject required a tone whose intensity was 46 decibels above pretest threshold level to produce detection. These curves indicate that slight sensitivity losses may occur very early during the vigilance session, accounting for the general elevation in threshold curves of Figures 1 and 2.

The bottom curve of each pair in Figure 5 shows the 3-min latency means corresponding to the threshold values above. While mean latency varied here between 0.5 - 2 sec, single values taken from the records of both experiments ranged between 0.2 - 5 sec, - 5 sec being the upper limit cutoff by the

presentation of the next tone. Since no cutoff for false-positive responses was employed, the latency means shown in this figure contain the occasional effect of random responding, and are thus somewhat inflated. This same effect is also operating in the threshold data of this figure, but here the effect is to depress the threshold. Threshold level and response latency, as shown by the curves in Figure 5, are uncorrelated.

#### False Positives:

False-positive responses - i.e., responses occurring between trains of tones - were variably distributed across conditions and trials of both experiments. Chi-squares of Friedman's non-parametric analysis of variance (Siegel, 1956, p. 166) showed that false-positive responding was unrelated to signal rate, and to sessions. These findings indicate that Ss, independent of any assignable criterion for signal occurrence, maintained a more or less fixed probability to report false alarms in the face of changing frequencies and intervals of signal occurrence throughout the six days of testing.

### SUMMARY

Vigilance performance consisting of auditory threshold, latency of response, and false-positive response measures were obtained from 24 Navy and civilian subjects during the course of six daily 48-minute monitoring sessions in which S pressed a microswitch to report single tones in signal trains of increasing intensity. Six signal densities from 2.5 to 120 signals per hour, and six intersignal intervals ranging up to 108 seconds around a signal rate of 1 per minute were found to have some differential effect on auditory threshold. An improvement of 3.25 dB in signal/noise detection occurred when signal density was increased from 2.5 to 15 per hour. Higher rates were not additionally effective. Below the rate of 15/hr, response latency increased regularly with the slower rates, though there was no further improvement with higher signal densities. Thus a rate of about 1 signal every four minutes was the most efficient density. Time-on-watch analysis revealed large individual differences. An analysis of false-positive responding indicated that false alarms were unrelated to signal rate, intersignal variability, or listening session.

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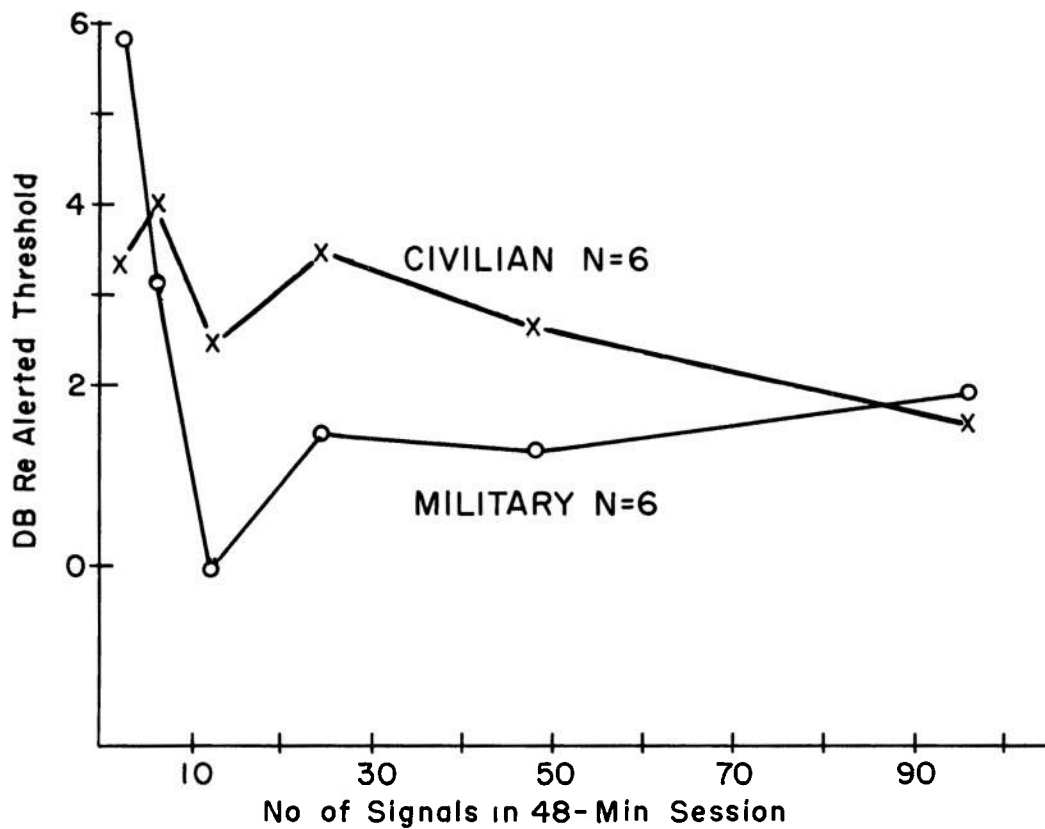


Figure 1 - Mean Detection in DB re Pre-test Threshold Zero as a Function of Signal Rate Note For each individual, the median threshold for each of 2, 6, 96 signals/session/computed, entry is mean of the 6 individual medians

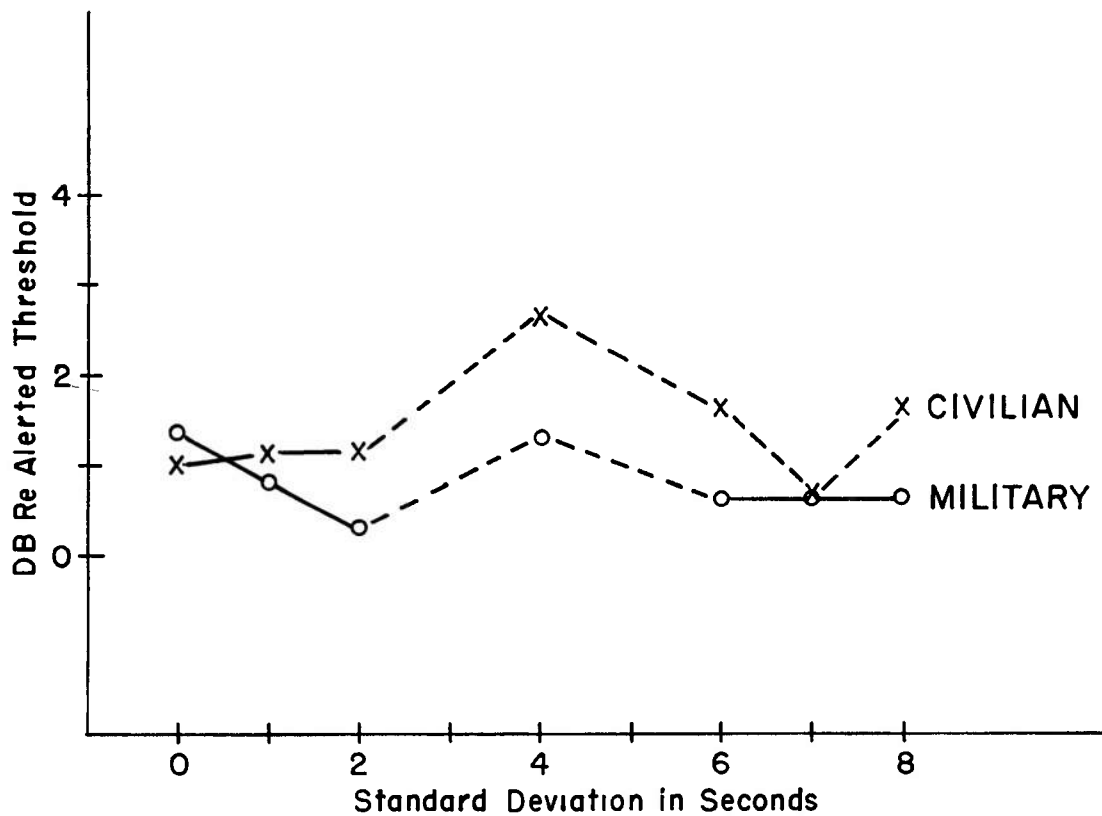


Figure 2 - Mean Detection in DB re Pre-test Threshold Zero as a Function of Variance in Interstimulus Interval Note For each individual the median threshold to 48 signals/session is computed at each of the distributions, entry is mean of the 6 individual medians

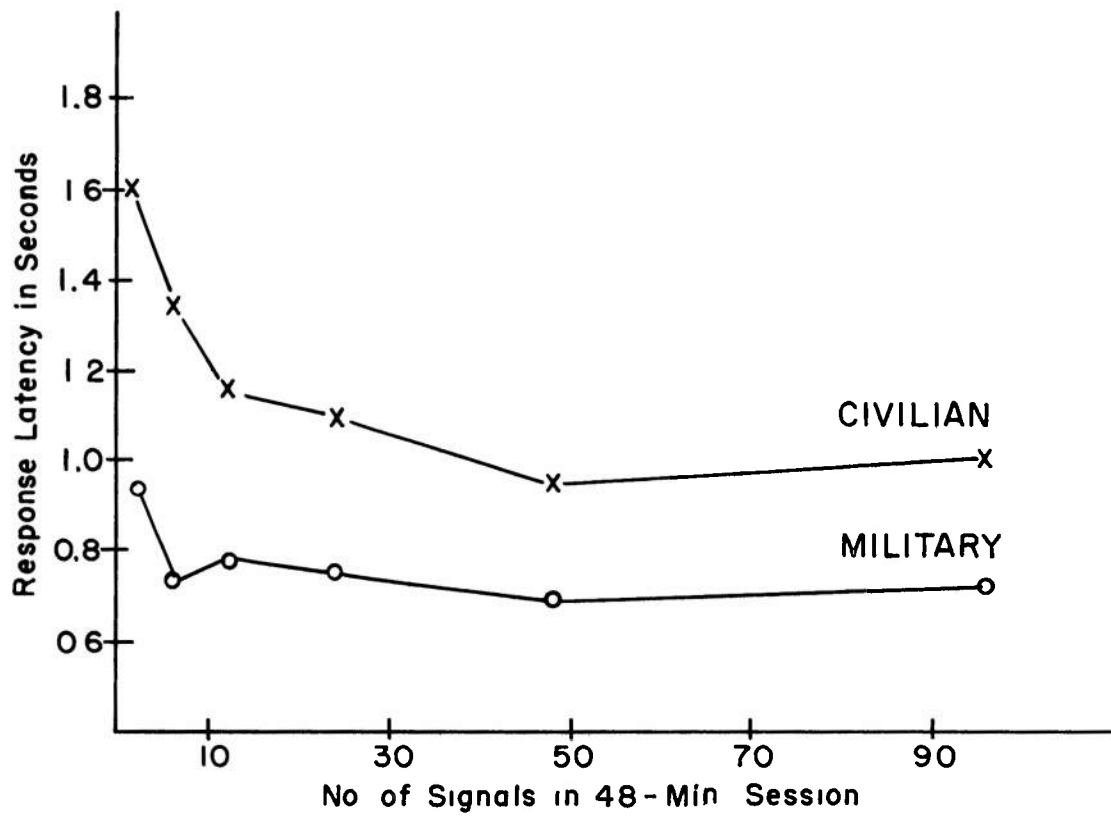


Figure 3 - Mean Latency in Seconds of Response as a Function of Signal Rate  
Entry computed as in Figure 1

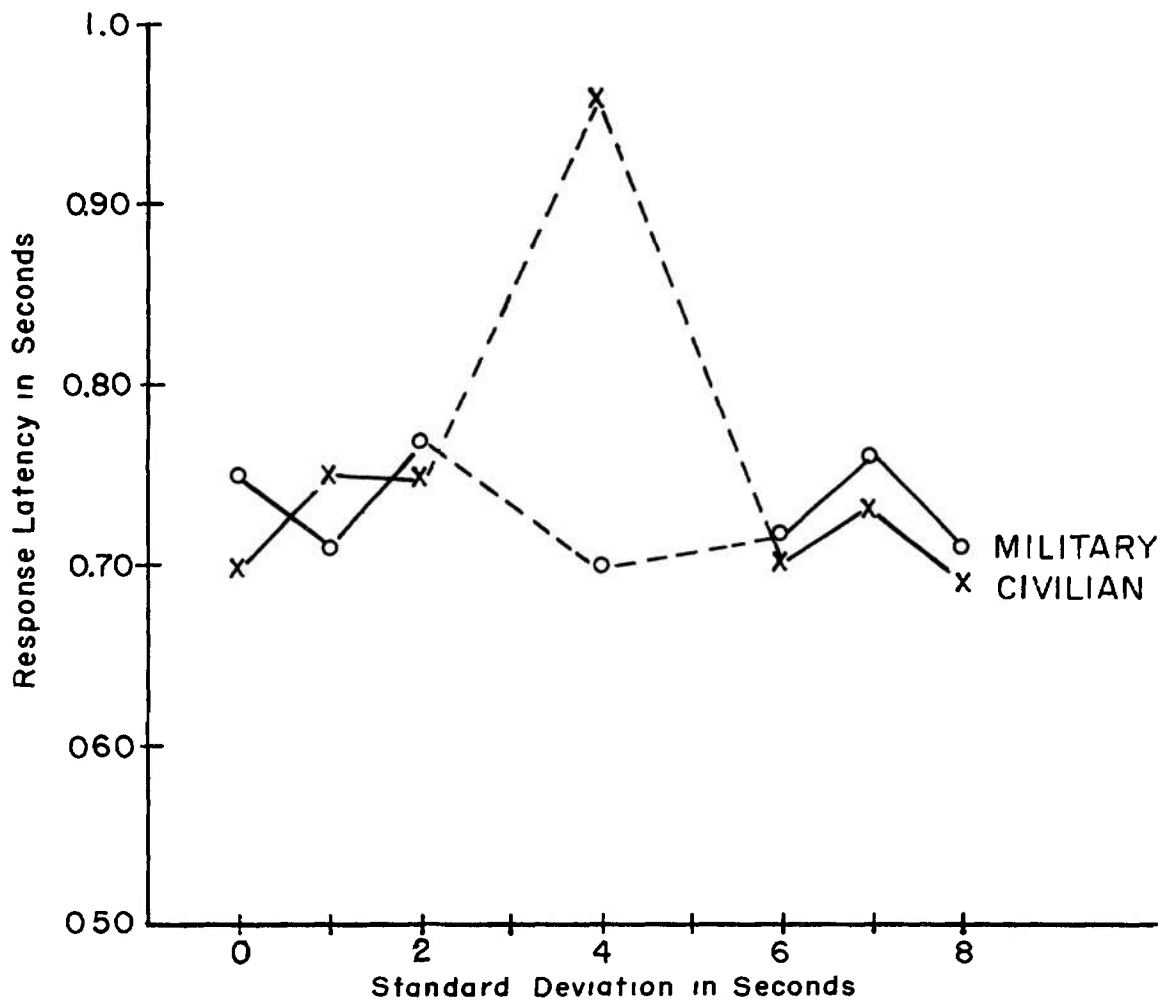


Figure 4 - Mean Latency in Seconds of Response as a Function of Variance in Interstimulus Interval Entry computed as in Figure 2



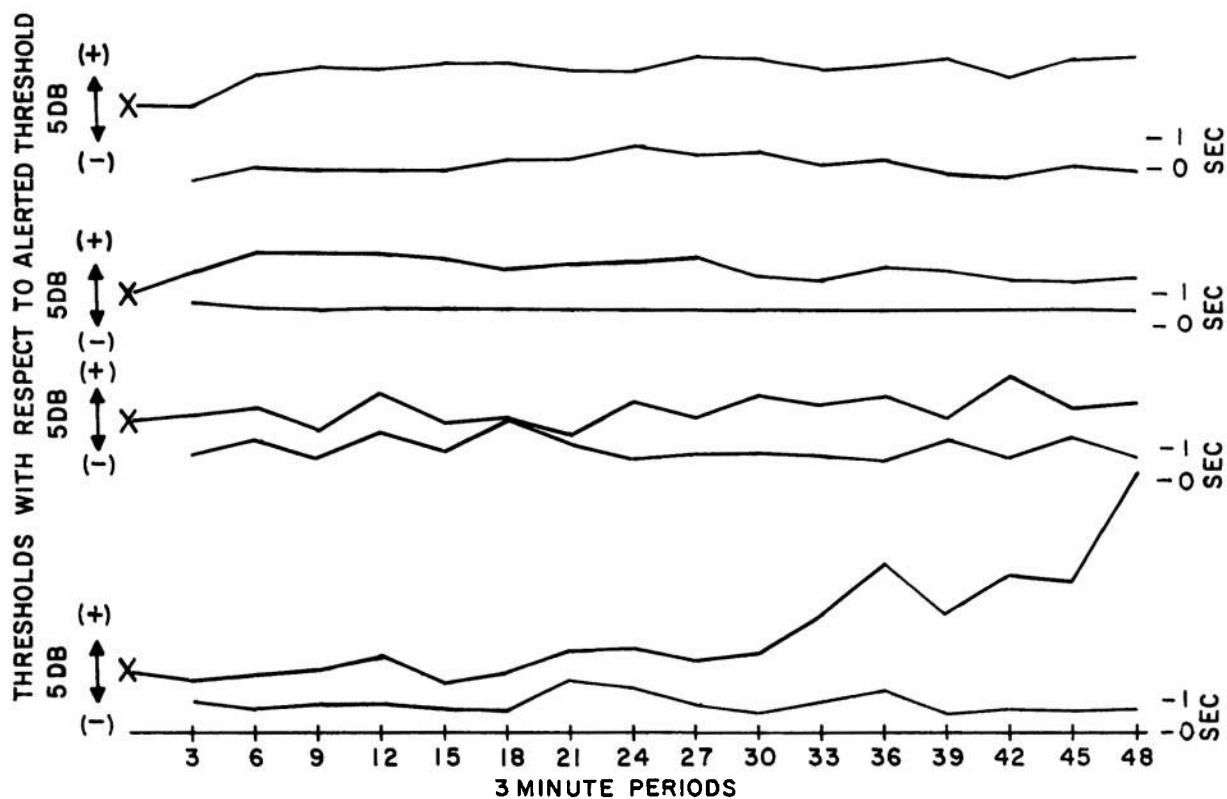


Figure 5 - Signal Density 2/Min Individual Subject Means every 3-Min of Threshold and Latency Response as a Function of Time on Watch. Threshold Values in DB on Left, Latency Values in Sec on Right.

TABLE I

## SUMMARY OF NUMERICAL RELATIONS AMONG INTERSIGNAL INTERVAL CONDITIONS

## Experiment I

| <u>Experimental Condition</u> | <u>Signal Rate<br/>(Signals/48 minutes)</u> | <u>Mean Interval<br/>in sec</u> | <u>Sigma<br/>in sec</u> | <u>Sigma/<br/>Mean Interval</u> | <u>Intervals<br/>in sec</u>     |
|-------------------------------|---|---------------------------------|-------------------------|---------------------------------|---------------------------------|
| # 1                           | 2   | 1440                            | 96                      | 1/15                            | 1152, 1728                      |
| # 2                           | 6   | 480                             | 32                      | 1/15                            | 384, 416, 448,<br>512, 544, 576 |
| # 3                           | 12  | 240                             | 16                      | 1/15                            | 192, 208, 224,<br>256, 272, 288 |
| # 4                           | 24  | 120                             | 8                       | 1/15                            | 96, 104, 112,<br>120, 136, 144  |
| # 5                           | 48  | 60                              | 4                       | 1/15                            | 48, 52, 56, 64,<br>48, 72       |
| # 6                           | 96  | 30                              | 2                       | 1/15                            | 24, 26, 28, 32,<br>34, 36       |

## Experiment II

|     |    |    |   |      |                           |
|-----|----|----|---|------|---------------------------|
| # 1 | 48 | 60 | 0 | 0/60 | 60, 60, 60, 60<br>60, 60  |
| # 2 | 48 | 60 | 1 | 1/60 | 57, 58, 59, 61,<br>62, 63 |
| # 3 | 48 | 60 | 2 | 2/60 | 54, 56, 58, 62,<br>64, 66 |
| # 4 | 48 | 60 | 6 | 6/60 | 42, 48, 54, 66,<br>72, 78 |
| # 5 | 48 | 60 | 7 | 7/60 | 39, 46, 53, 67,<br>74, 81 |
| # 6 | 48 | 60 | 8 | 8/60 | 36, 44, 52, 68,<br>76, 84 |

TABLE II

SUMMARY OF ANALYSES OF VARIANCE FOR EVALUATING THE EFFECT OF SIGNAL RATE,  
ORDER, AND SESSIONS ON SIGNAL DETECTION THRESHOLD (RE "RELATIVE DB ZERO") AND LATENCY

| Source  | df | MS<br>in db | F<br>in db        | MS<br>latency<br>in sec | F<br>latency<br>in sec |
|---|----|-------------|-------------------|-------------------------|------------------------|
| Order   | 5  | 9.56        | 3.57              | 0.62                    | ---                    |
| Error (between Ss)                              | 6  | 2.68        |                   | 1.38                    | ---                    |
| Total (between Ss)                              | 11 | 5.80        |                   | 1.34                    |                        |
| Signal Rate                                     | 5  | 4.61        | 2.45              | 0.31                    | 4.43                   |
| Sessions  | 5  | 0.96        | ---               | 0.14                    | 2.00                   |
| Error (Latin Square)                            | 20 | 1.88        | 2.94 <sup>-</sup> | 0.03                    | 0.33                   |
| Error (within Ss)                               | 30 | 0.64        |                   | 0.09                    |                        |
| Total (within Ss)                               | 60 | 1.41        |                   | 0.91                    |                        |
| Total   | 71 |             |                   |                         |                        |
| Navy-Civilian                                   | 1  | 1.84        | ---               | 3.23                    | 46.14 <sup>-</sup>     |
| Combined Error (Latin<br>Square plus Within Ss) | 50 |             |                   | 0.07                    |                        |

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F .95

<sup>-</sup> F .99

TABLE 111

SUMMARY OF ANALYSES OF VARIANCE FOR EVALUATING  
 THE EFFECT OF SIGNAL DISTRIBUTION, DISTRIBUTION ORDER,  
 AND SESSIONS ON SIGNAL DETECTION THRESHOLD (RE "RELATIVE DB ZERO") AND LATENCY

| Source  | df | MS<br>in db | F<br>in db | MS<br>latency<br>in sec | F<br>latency<br>in sec |
|---|----|-------------|------------|-------------------------|------------------------|
| Order   | 5  | 2.00        | ---        | 0.15                    | 1.25                   |
| Error (between Ss)                              | 6  | 2.93        | ---        | 0.12                    |                        |
| Total (between Ss)                              | 11 | 2.51        |            | 0.13                    |                        |
| Signal Distribution                             | 5  | 0.15        | ---        | 0.01                    | 1.00                   |
| Sessions  | 5  | 0.16        | ---        | 0.03                    | 3.00                   |
| Error (Latin Square)                            | 20 | 0.44        | 1.15       | 0.01                    | 1.00                   |
| Error (within Ss)                               | 30 | 0.38        |            | 0.01                    |                        |
| Total (within Ss)                               | 60 | 3.60        |            | 0.01                    |                        |
| Total   | 71 |             |            |                         |                        |
| Navy-Civilian                                   | 1  | 1.01        | 2.52       | 0.01                    | ---                    |
| Combined Error (Latin<br>Square plus Within Ss) | 50 | 0.40        |            | 0.01                    |                        |

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| 13 ABSTRACT<br><p>Vigilance performances consisting of auditory threshold, latency and false-positive responses measures were obtained from 24 Navy and civilian subjects during the course of six daily 48-minute monitoring sessions in which Ss pressed a microswitch to report single tones in signal trains of increasing intensity. Six signal densities from 2 5 to 120 signals per hour, and six intersignal intervals ranging from 0 to 108 seconds around a signal rate of one per minute were found to have no differential effect on auditory threshold. An improvement of 3 25 dB in signal/noise detection occurred when signal density was increased from 2 5 to 15 per hour. Higher rates were not additionally effective. Below the rate of 15/hour, response latency increased regularly with the slower rates, though there was no further improvement with higher signal densities. Thus a rate of about one signal every four minutes was the most efficient density. Time-on-watch analysis revealed large individual differences. An analysis of false-positive responding indicated that false alarms were unrelated to signal rate, intersignal variability, or listening session.</p> |                            |  |  |

|                      |        |    |        |    |        |    |
|----------------------|--------|----|--------|----|--------|----|
| 14<br>KEY WORDS      | LINK A |    | LINK B |    | LINK C |    |
|                      | ROLE   | WT | ROLE   | WT | ROLE   | WT |
| Signal detection     |        |    |        |    |        |    |
| Auditory vigilance   |        |    |        |    |        |    |
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**14 KEY WORDS** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional